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BOOK REVIEW

William R. Uttal: Mind and Brain: A Critical Appraisal of Cognitive Neuroscience

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The relation between mind and brain is one of the big scientific questions that has attracted scientists' attention for centuries but also eluded their understanding. In this book, William Uttal provides a critical review of cognitive neuroscience, focusing on a specific question: What do the brain-imaging techniques developed in the last two decades or so—mostly functional magnetic resonance imaging (fMRI) and positron emission tomography (PET)—tell us about the brain-mind problem? His unambiguous and abrasive answer is: nothing.

The book is organized in nine chapters. The introductory chapter provides historical, methodological, and philosophical background. Importantly, it highlights a shift in the way neuroscientists think about modularity and localization. Traditionally, researchers using brain imaging have tended to subscribe to a strong view of modularity and localization, where distinct cognitive modules are assumed to be localized in well-defined regions of the brain. In the last decade, however, there has been a trend towards considering widely distributed networks of modules rather than isolated modules, as was the case earlier.

The following five chapters deal with different empirical domains, and roughly follow the same pattern: first, a presentation of psychological and behavioral aspects of the issue; second, a discussion of the results collected in traditional neuroscience before the advent of PET and fMRI; and third, an evaluation of the results obtained by modern cognitive neuroscience using recent brain-imaging techniques. Chapters 2 and 3 cover sensation and perception. Chapter 4 discusses emotion and affect. Chapter 5 is devoted to learning and memory. Chapter 6 addresses attention. Finally, chapter 7 covers consciousness and other high-level cognitive processes. The last two chapters address broader issues. Chapter 8 discusses applications of brain-imaging research and covers topics such as lie detection, autism, and neuro-

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marketing. It strongly warns that these applications go considerably beyond what is known scientifically. The final chapter draws implications from the research reviewed in previous chapters and proposes a new brain metaphor, where localization and modularity are replaced by widely distributed and fluid systems.

Uttal is obviously not sympathetic with contemporary cognitive neuroscience and its emphasis on modularity and localization. He describes himself as a radical behaviorist, thus denying hypothetical cognitive processes and a fortiori their link to brain structures. He has written several books critical of cognitive neuroscience and cognitive psychology (in particular, see Uttal 2001). However, he does recognize the utility of MRI for anatomical and physiological investigations, and he also agrees that robust data have been collected about sensory and motor processes.

In *Mind and Brain*, Uttal uses seven lines of argumentation. First, fMRI experiments using cognitive tasks lack reliability. They have a low statistical power, in part due to the small number of participants involved. In addition, few experiments are directly replicated. When they are replicated, the conclusion of meta-analyses is not that few localized areas are activated, but that virtually the entire brain is activated in any cognitive task, even with those of little complexity. (This point is explored is more detail in a companion book, Uttal 2012.) While in most sciences additional experiments help obtain increasingly precise measures, the opposite seems true with brain imaging: measures become increasingly diffuse. This result directly contradicts two key assumptions of modern cognitive neuroscience—localization and modularity. These conclusions are shared by other authors (e.g., Bennett and Miller 2010; Button et al. 2013; Carp 2012; Nieuwenhuis et al. 2011). Whether these disparities are due to inter-individual differences, inadequate measures or the very nature of the brain-mind relationship is open to debate.

Second, and related to the first point, there are serious methodological issues in the way brain-imaging data are analyzed. This is in part due to the unconstrained way in which statistical analyses can be carried out. For example, Ihnen et al. (2009) found sex differences in two language tasks. However, when they randomly assigned males and females to two groups, they also found differences in the brain regions activated that could be explained by sex-difference theories. Vul et al. (2009) carried out a meta-analysis of studies linking personality and brain activity. They found that many of these correlations were higher than the reliability of the personality tests used in the studies—a statistical absurdity. They argue that a common source of spurious results in brain-imaging research is due to what they call “double dipping”: the same data are used to identify regions of interest in the brain and then to correlate activity in these regions with other measures.

Third, the macro-level at which brain imaging techniques such as fMRI, PET, and EEG collect data is the wrong level of analysis, both temporally and spatially. The correct level to understand how the brain underpins the mind is the level of neurons and networks of neurons (neuronal level), not the aggregate level used by brain-imaging techniques. The issue is that these techniques lose a considerable amount of information; in particular, they lose virtually all the information about what is going on at the level of neuronal circuits, which is where the real action is if one wants to understand cognition.

Fourth, cognitive neuroscience uses a theoretical language that is poorly specified, where concepts are ill-defined and vague. Cognitive neuroscience inherits this problem from psychology, where vague and ambiguous theories abound.

Fifth, the language used to describe the brain in the literature is inconsistent—Uttal notes three different systems (the system denoting the major gyri and sulci of the brain, Brodmann system, and Talairach and Tournoux coordinate system), which all have their problems and which do not map perfectly into one another. This often makes it difficult to compare experimental results as papers use different notational systems.

Sixth, the quality of brain-imaging data as compared to behavioral data is vastly exaggerated. There is a striking difference between behavioral measures such as percentage correct and reaction times, on the one hand, and brain-imaging data, on the other hand. The former are direct measures that are immediately meaningful; the latter have to go through a number of pre-processing, filtering, and smoothing steps that makes them very indirect indeed. My own experience with fMRI and EEG (Campitelli et al. 2007; Wright et al. 2013) has certainly made me aware of how correct Uttal is on this point.

Finally, at the risk of stating the obvious, the brain is extremely complex. As noted by Uttal, the estimated number of neurons ranges from 10 billion to 1 trillion, and the average number of synapses per neuron is perhaps between 5,000 and 10,000. For Uttal, this should lead to pessimism as to whether we will ever understand the human brain. In addition to obvious practical difficulties, Uttal also mentions theoretical reasons as to why a full understanding might be elusive. In particular, Moore's theorem (Moore 1956) states that the workings of a system cannot be fully identified from input-output relationships only, and complexity theory suggests limits in our understanding of hierarchical structure of complex systems such as the visual system (Hilgetag et al. 1996).

At the end of his review of brain-imaging research, which covers a sizeable subset of a massive literature, Uttal concludes that the two dominant views (localized nodes and networks of localized nodes) are incorrect. Rather, he proposes that the brain is best described as a distributed system, although without going as far as Lashley's equipotentiality hypothesis (Lashley 1950). By contrast to the approaches based on localization, he argues that the boundaries of the brain regions involved in cognitive tasks are fuzzy and fluid, for example being rapidly redrawn with new task demands.

Is the field of cognitive neuroscience in serious trouble? This is clearly what Uttal thinks, and I believe that his conclusion is correct. Beyond methodological and statistical problems, which have been known for a while, Uttal's best argument is empirical in nature and is worth repeating: when the results of diverse experiments studying a specific cognitive function are put together, the pattern that emerges is not a set of a few distinct brain areas but a large subset of the brain. This unexpected result refutes the twin key assumptions of modularity and localization and thus strikes at the heart of cognitive neuroscience.

What can be done about this state of affairs? According to Uttal, the best course of action would be first to abandon brain-imaging research and revert to more traditional behavioral methods, and second to focus on theories postulating broadly distributed systems. In my view, the first course of action is unlikely to happen, given the scientific appeal of modularity, the number of researchers currently carrying out brain-imaging research and the substantial amounts of money that universities and research centers have invested in costly apparatus such as fMRI scanners. By contrast, the second course of action might well happen, although the hypotheses of modularity and localization will not disappear fully, as part of the data seem to support them.

Most of the criticisms made by Uttal seem valid and convincing. Indeed, many have been long known in the field, though not always publicly acknowledged. It is only recently that a slew of papers in cognitive neuroscience have addressed the very same methodological issues of validity, replication, and statistical power addressed by Uttal. In any case, Uttal's important contribution is to have put these criticisms together, and to have linked them to more epistemological issues.

There is one criticism that I found unconvincing. Uttal argues for a strong version of behaviorism, rejecting the kind of concepts and mechanisms postulated by cognitive psychology and cognitive neuroscience. This is a weak point of the book, though admittedly Uttal refers the reader to another source for a more in-depth discussion. Theoretical constructs, such as planning, inhibiting and short-term memory in psychology, which are not observable but are part of theories and help them make predictions, are common place in all sciences, including physics and biology. Behaviorists' insistence on denying them is simply inconsistent with common practice in science.

By contrast, Uttal is in a strength position when he criticizes the poverty of theories in cognitive neuroscience. Indeed, I would argue that, theoretically, cognitive psychology has made one step backward with the advent of brain-imagining techniques. The detailed information-processing models characterizing cognitive psychology have been replaced by theories that essentially limit themselves to describe correlations between brain areas and cognitive functions. This does not tell us much about the causal mechanisms involved and provides only minimal constraints on further theory development. Incidentally, this linkage is sometimes done with disarming naiveté, for example when researchers claimed to have discovered the brain centers for creativity, love, or honesty. Whether cognitive functions are localized or distributed is an open empirical question. However, proponents of brain modularity (either as distinct modules or as modules distributed in networks) or non-modularity should use more detailed and explanatory theories than has been the case so far.

Uttal does not say much about computational approaches to the study of mind and brain, and this is regrettable. Two approaches might be highlighted here. The first is the research by John Anderson et al. around the ACT-R cognitive architecture (Anderson et al. 2004). This group has systematically connected the mechanisms postulated by ACT-R with cortical and subcortical structures, validating their architecture by using fMRI results in addition to traditional measures such as errors and reaction times. Thus, the validity of both the postulated mechanisms and their link with brain structures can be systematically tested. The second approach consists in using evolutionary computation to automatically generate scientific theories linking cognitive functions to neural structures (Frias-Martinez and Gobet 2007; Gobet and Parker 2005). The method relies on the assumption of modularity but also provides a test of the validity of this assumption. Given the complexity of the empirical data available, only such formal approaches can help make sense of them.

Overall, *Mind and Brain* is clearly written and well documented. Given the considerable ground covered, the use of interim conclusions at the end of most chapters is welcome. The book is somewhat repetitive; this is due in part to its organization, where the different traditional fields of research (sensation/perception, memory, etc.) are critically evaluated using the same criteria. The style is lively and abrasive at times, which makes for entertaining reading but is also likely to infuriate many readers. The book raises fundamental epistemological, methodological, and empirical questions about cognitive neuroscience and in particular brain imaging. Given that similar questions have recently been raised by several leading neuroscientists, the timing is perfect. There is serious soul searching to be done for cognitive neuroscience.

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